National Research Council Canada
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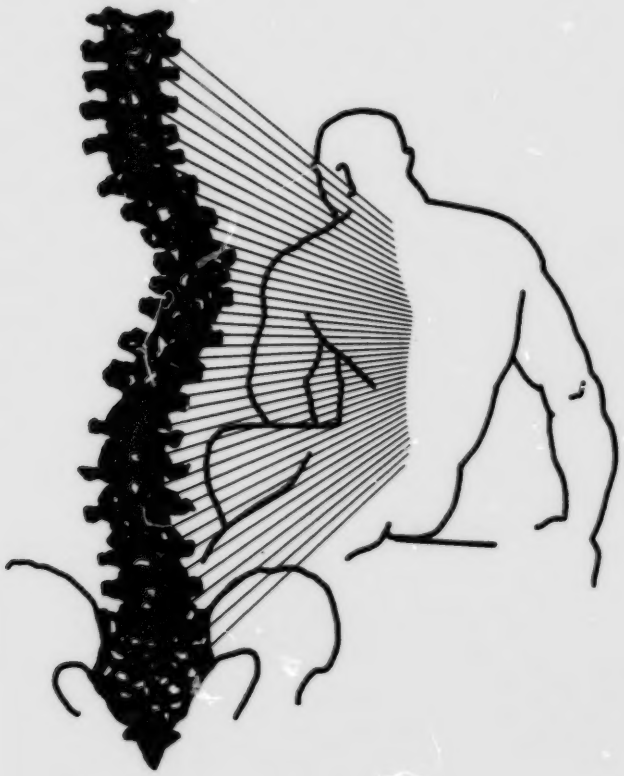
Fourth International Symposium on Surface Topography and Spinal Deformity

PROGRAM AND ABSTRACTS



September 29 - 30, 1986

Monte Ste Marie Conference Centre
Lac Ste Marie, Québec, Canada

Edited by: J.R. PEKELSKY

NRCC 26205

87-04646/

Fourth International Symposium on Surface Topography and Spinal Deformity

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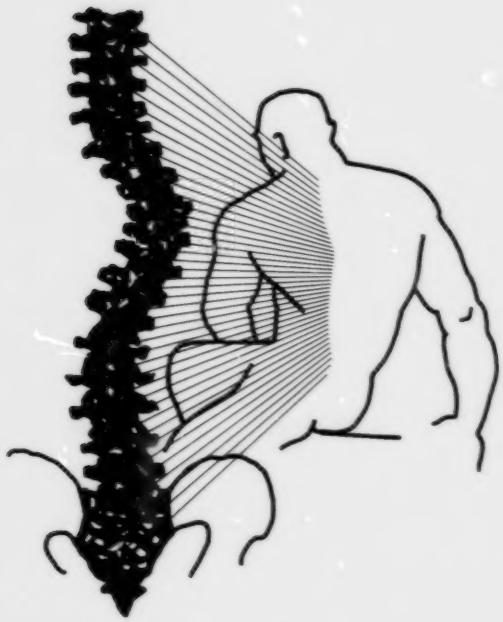

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PROGRAM CHANGE

PLEASE NOTE THAT THE FOLLOWING
PAPER HAS BEEN ADDED TO THE PROGRAM

Tuesday Session T4: (J.R.Pekelsky, Chairman)

Paper #5:

F. R. Livingstone and A. Tulai (Ottawa)

"Surface Measurement using the
HYSCAN 3-D Camera"

ERRATA: Authors citing papers from this meeting are cautioned that "Mont Ste Marie" was misspelled on the cover and title page of the Program and Abstracts book.

FOURTH INTERNATIONAL SYMPOSIUM ON SURFACE TOPOGRAPHY AND SPINAL DEFORMITY

Final Program

Sunday, September 28th

16:00–19:00 Registration
18:00 Dinner
20:00 Reception (Wine and Cheese)

Monday, September 29th

7:00–8:15 Breakfast
8:00–8:30 Registration
8:15–8:30 Welcome and Introductory Remarks

8:30–10:15 **SESSION M1:** E. Hierholzer (Chairman)

SPINAL DEFORMITY AND SURFACE RELATIONSHIPS

D. N. Ghista, G. R. Viviani and D. Miller (Hamilton) 6
"From back topography to spinal deformity estimation and correction - a justifiable problem?"

A. R. Turner-Smith (Oxford) 7
"Some relationships between the spine and skin surface shape"

J. Raso, B. Greenhill, M. Moreau and D. Budney (Edmonton) 8
"The combined reconstruction of spinal and surface deformity"

J. Csongradi, R. J. Jefferson, A. R. Turner-Smith and J. D. Harris (Stanford) . 9
"Predictive value of surface topography in the management of scoliosis"

G. R. Houghton, R. J. Jefferson, D. C. Thomas, J. D. Harris and A. R. Turner-Smith (Oxford) 10
"The effect of scoliosis surgery on back shape"

Z. Dvir and K.Weigel (Tel-Aviv) 11
"A novel device for moiré patterns: applications in supine position topography"

10:15–10:45 Coffee break (Note: Posters will be on display in the lounge.)

S. A. Kamal (Baltimore) [Poster, with paper in Proceedings] 12
"Moiré topography for the study of multiple curves in the spine"

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10:45–12:00 **Session M2:** A. R. Turner-Smith (Chairman)

RIB CAGE DEFORMATION AND SPINAL ROTATIONS

P. H. Dangerfield and J. S. Denton (Liverpool) 13
"The assessment of rib cage deformity in scoliosis"

J. Dansereau, I. A. F. Stokes and M. S. Moreland (Burlington) 14
"Radiographic reconstruction of 3-D human rib cage"

J. Dansereau, I. A. F. Stokes and M. S. Moreland (Burlington) 15
"Rib cage rotation, spinal deformity and surface topography"

J. D. Harris, R. J. Jefferson, A. R. Turner-Smith and D. Thomas (Oxford) . 16
"Transverse asymmetry measured by
ISIS and vertebral rotation"

12:00–13:30 Lunch Break

13:30–15:00 **Session M3:** H. Neugebauer (Chairman)

CLINICAL STUDIES AND SURVEYS I

R. Assente, G. Ferrigno, G. C. Santambrogio and R. Vigano' (Milano) . . . 17
"Application of AUSCAN system for evaluation
of postural changes induced by a brace"

A. Alberti (Lisbon) 18
"Moiré and deformities of the vertebral column"

A. Shinoto, Y. Ohtsuka and S. Inoue (Yokohama) 19
"Three-dimensional analysis of the effect of brace treatment on
idiopathic scoliosis"

G. E. Karras and K. N. Tympanidis (Athens) [only in printed Proceedings] . 20
"Measuring changes in posture during pregnancy"

R. G. Burwell (Nottingham) 21
"A multicentre study by the British Scoliosis Society
on back shape in 5350 healthy children"

15:00–15:30 Coffee break

15:30–17:00 **Session M4:** M. S. Moreland (Chairman)

CLINICAL STUDIES AND SURVEYS II

A. R. Turner-Smith, J. D. Harris and D. Thomas (Oxford) 22
"The international assessment of back shape and analysis using ISIS"

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E. S. Duff and E. R. C. Draper (Edinburgh) 23
"Survey of normal adolescent back shape as measured by ISIS (Integrated Shape Investigation System)"

H. Bergenudd and S. Willner (Malmö) 24
"A study of the lateral curves of the spine in teenagers and middleagers with a spinal pantograph"

H. Neugebauer and G. Windischbauer (Vienna) 25
"School screening: a new pilot study in Vienna"

U. J. L. Nicholson, R. G. Burwell, S. S. Upadhyay and J. K. Webb (Nottingham) 26
"Kyphosis and lordosis measured by ISIS: an appraisal on a plaster model, healthy subjects and patients with low back pain and scoliosis"

19:00 **Symposium Banquet**

(Guest Speaker: R. Herron on "The shape of things to come!")

Tuesday, September 30th

7:00–8:15 Breakfast

8:15–10:00 **Session T1:** S. Willner (Chairman)

COMPARATIVE STUDIES

M. S. Moreland and I. A. F. Stokes (Burlington) 27
"Back shape and scoliosis: a comparison of measurement techniques"

G. Schumpe, H. Messler, A. Heep and H. Rössler (Bonn) 28
"Comparison of determination parameters of spinal deformity by using optrimetric, ultrasound and x-ray methods"

G. Benoni, A. R. Turner-Smith and S. Willner (Malmö) 29
"A comparison between ISIS and the moiré method in the assessment of scoliosis"

M. Van Poucke, M. Vercauteren, P. Boone and W. De Coster (Ghent) . . . 30
"Comparative study between the ISIS, moiré topography and the Sangamo Transformer in the detection of scoliosis"

S. S. Upadhyay, R. G. Burwell and J. K. Webb (Nottingham) 31
"ISIS and the Scoliometer: hump dynamics in patients with idiopathic scoliosis"

G. Snewing, B. Ngcobo and L. Breckhoven (Kingston) 32
"A comparative study of sagittal spinal thorac-lumbar curves using flexible rule and moiré contourgraphy"

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10:00–10:15 Coffee break

10:15–12:00 **Session T2:** R. Herron (Chairman)

BODY SHAPE ANALYSIS AND REPRESENTATION

G. Windischbauer and H. Neugebauer (Vienna) 33
"The analysis of human back shape asymmetries by computer algorithms"

E. Hierholzer and B. Drerup (Münster) 34
"Shape analysis of the human back: automatic localization of anatomical landmarks and assessment of lateral asymmetry"

B. Drerup and E. Hierholzer (Münster) 35
"Shape analysis of the back surface: measurement of the lateral tilting of the pelvis from posterior superior iliac spines"

M. A. Bannon and S. Tredwell (Vancouver) 36
"Variability due to subject positioning"

M. Lord (London) 37
"Foot shape representation for a CAD application"

T. J. Jones, E. R. Scull, K. E. Dutton, B. S. Slinger and J. C. B. O'Conner (Perth) 38
"Analytic assessment of back symmetry and its reliability in a clinical setting"

12:00–13:30 Lunch Break

13:30–15:00 **Session T3:** B. Drerup (Chairman)

SURFACE TOPOGRAPHY

MEASUREMENT TECHNIQUES I

S. O'N. Daunt, I. D. Swain, J. C. Robertson, G. Wu and M. Nur (Salisbury) 39
"Dynamic moiré topography for the assessment of spinal deformity"

N. Suzuki, T. Ono and M. Akamatsu (Tokyo) 40
"Real time analysis of moiré pictures in the scoliosis clinic"

J. R. Pekelsky (Ottawa) 41
"Moiré topogram production and analysis at NRC: a status report"

X. H. Ding and J. R. Pekelsky (Ottawa) 42
"Photometric ordering of ordinary moiré fringes"

R. R. Real and Y. Fujimoto (Ottawa) 43
"Electronic imaging, processing and storage applied to scoliosis screening"

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15:00–15:30 Coffee break

15:30–16:45 **Session T4:** J. R. Pekelsky (Chairman)

SURFACE TOPOGRAPHY

MEASUREMENT TECHNIQUES II

K. Ong, M. Khan, S. H. Boey, K. N. Ngan, J. Daruwalla (Singapore) . . . 44
"Moiré contourgraphy on a microcomputer-based image processing system for the detection of scoliosis"

G. D'Abramo, G. Lorini and A. Merolli (Rome) 45
"Computer-assisted dot array analysis in surface topography: perspectives for clinical screenings in scoliosis"

R. Assente, N. A. Borghese, G. Ferrigno, and G. C. Santambrogio (Milano) . 46
"AUSCAN system: technological features of the new 3-D version"

T. Yoshizawa, Y. Ohtsuka, Y. Okamoto, A. Shinoto and K. Kimoto (Tokyo) 47
"Automatic 3-D measurement by the projection of a grating pattern"

16:45–17:15 Concluding Remarks and Business Meeting

18:00 Dinner

Wednesday, October 1st

7:00–8:30 Breakfast

9:00 Bus to Ottawa and NRC Labs Tour

10:30–16:00 Tour of NRC Photogrammetry Labs

12:00,14:00,16:00 Bus from NRC to Ottawa Airport

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From back topography to spinal deformity estimation and correction - a justifiable problem?

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Scoliosis is a coupled 3-dimensional deformity. The rotational deformity is a consequence of lateral deformity superimposed on the natural kyphotic and lordotic deformity of the spine. The rotation further varies, both in magnitude and sense, along the spine. Additionally, the spinal deformity, when radiographed, appears different in different oblique views and the deformity often appears exaggerated in oblique views relative to the A-P view. This provides a clue that lateral distraction cannot adequately correct scoliotic deformity, nor can laterally applied tractions in the A-P view. To this end a new approach to spinal correction is developed.

Based on our clinical data, surface parameters as such do not bear one-to-one correspondence with conventional scoliotic deformity parameters such as the Cobb angle. Hitherto empirical attempts to do so would not have had a scientific basis. In order to obtain such a correlation, a mathematical analysis in the realm of topography would be needed to demonstrate the surface produced by sequential superimposed deformations of the spine. However, while the forward problem is tractable, the inverse problem does not bear a unique solution.

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Some relationships between the spine and skin surface shape

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The analysis of surface shape of scoliotic backs presented by ISIS scanning includes estimations of the line of the underlying spine and the position and angle of the end vertebrae of the curve.

The line of the spine is calculated from the position of marks placed over the palpable spine, with an extra factor representing vertebral rotation in the horizontal plane. This rotation is estimated from the angle of the skin over the vertebrae at each level.

The end vertebrae of a scoliotic spine, from which the Cobb angle is measured, are assumed to lie at the points of inflexion of the line of the spine in the coronal view. However, on average, a line constructed at right angles to the line of the spine lies at a steeper angle than a line drawn across the endplates of the end vertebrae at the same level on the corresponding radiograph. The measure of lateral asymmetry on the ISIS scan takes into account this difference in order to correspond more clearly to the Cobb angle.

A series of spinal radiographs have been examined to explore the normal relationship between the line of the vertebral bodies and the angles of the endplates of the end vertebrae.

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The combined reconstruction of spinal and surface deformity

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The relationship between internal spinal alignment and external trunk deformity in idiopathic scoliosis is poorly understood. Children with a mild spinal curvature may exhibit marked trunk asymmetry. Our aim is to establish a system that describes the complete deformity in scoliosis. This paper details a method of combining the internal configuration of the spine obtained from AP and lateral radiographs with surface data from moiré photographs.

The radiograph images are obtained with the subject in a standardised position frame. Scale markers are included in the radiographs which permit the true spatial configuration of the spine to be determined from the distorted AP and lateral radiographs. The location of the vertebral body centroids and selected vertebral rotations are calculated. The moiré image is obtained with the patient in a similar position frame. Three additional markers are used to match the spinal configuration with the surface topography.

Twelve subjects have been analyzed to date. With the L5 markers superimposed, the initial mismatch of the other two markers ranged from -5 ± 4 mm to 12 ± 7 mm. The data from the moiré image was further processed to minimize this mismatch, so that the final error was -1 ± 3 mm.

This method of combining the spinal and trunk deformities associated with idiopathic scoliosis is reliable and is incorporated easily into the clinic.

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Predictive value of surface topography in the management of scoliosis

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and

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The objective of this study was to find a reliable indicator from the Oxford ISIS scan of significant curve increase in idiopathic scoliosis, and to determine the accuracy of the ISIS indicator alone in predicting curve progression and need for spinal fusion.

The study group comprised 34 patients, aged 11–17, selected at random from the clinic population at the Nuffield Orthopaedic Centre. Criteria for inclusion in the study were:

1. Diagnosis of idiopathic scoliosis;
2. Cobb angle between 10° and 50° at initial visit;
3. At least 3 ISIS scans with no intervening surgical treatment, spaced by at least 3 months over a period of not more than 18 months;
4. No systemic disease or associated musculoskeletal problem.

An orthopaedic surgeon from another centre (JC) was provided with the following information on the study group:

1. Name, birthdate and sex of the patient;
2. Initial PA radiograph (unmarked);
3. Three longitudinal ISIS scans, the first coinciding with the initial radiograph.

Based only on the information provided, the observer assessed:

1. Occurence and magnitude of curve progression, defined as an increase in Cobb angle of 5° or more;
2. Whether the patient was or would be a candidate for surgery. The criterion for this decision was a predicted Cobb angle of 50° in the thoracic region at skeletal maturity;
3. The most reliable ISIS indicator of significant curve change.

The ISIS parameter which correlated best with the Cobb angle was the lateral asymmetry index ($r = 0.73$, $p = 0.001$), and this was also the most sensitive predictor of curve progressions. Based on the ISIS scans, 19 of the 34 curves were labelled progressive (56%), with a recommendation for spinal fusion in 9 of these patients. Final radiographs revealed that 12 curves progressed, and 11 (91%) of these were identified by the ISIS scan. The false negative rate was 1/34 (3%) and the false positive rate 8/34 (23%). All surgical candidates were identified.

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The effect of scoliosis surgery on back shape

G. R. Houghton, R. J. Jefferson, D. C. Thomas, J. D. Harris and A. R. Turner-Smith
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Headington, Oxford OX3 7LD, England

Thirty patients with idiopathic scoliosis have been assessed by x-rays and ISIS, both before and after surgery. Among the patients who had Harrington instrumentation there was little change in volume of rib prominence as measured 'ISIS volume'. However, the 'volume density' (ISIS volume/curve length) was more reduced by surgery, indicating that the rib prominence had been elongated and flattened by spine distraction. Furthermore, 'area differences' at various levels showed that the cross sectional area of maximum rib prominence was generally shifted caudad by surgery. Lateral asymmetry and Cobb angle measurements showed highly significant corrections after surgery. These corrections were reflected less strongly by the more subtle estimations of back shape – the ISIS volume, area difference and surface angle.

Sublaminar wiring was carried out only in idiopathic scoliosis when extreme lordosis was present. ISIS results show that lordosis was corrected by this procedure. Costaplasty was carried out if severe deformity persisted after spinal fusion. All ISIS criteria showed a great improvement in back shape measurements.

We conclude that cosmetic deformity of the back in scoliosis is only partially improved by operations on the spine, whilst costaplasty addresses the problem directly and clearly improves back shape appearance.

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A novel device for moiré patterns: applications in supine position topography

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Israel

One of the major drawbacks of Shadow Type Moiré Topography (STMT), is its vulnerability to random movements of the patient which might result in nonidentical contour patterns on different occasions. Apart from lowering the reliability of the technique it often increases the number of false positives. In addition, standard STMT devices allow examination in the upright position only, thus excluding the application of this technique from, for example, spinal flexibility assessment, follow up of spinal changes during traction, detection of morphological parameters in babies, etc. In Hasharon Hospital, a new STMT device has been designed and developed which overcomes the above limitations. The system mainframe consists of a mobile stretcher, the upper member of which has been removed to enable the introduction of a tubular structure, here to fore the *base*, consisting basically of two parallel rails. Along these rails another mobile structure, to which the camera and projector are attached, moves toward or away from an upright grid, made of colluloid, 50×60 cm in size. The vertical position of the base is controllable using an electric motor, enabling convenient positioning of the grid according to the patient's height. Also, the base may be moved horizontally, using a manual handle, toward or away from the patient who is comfortably supported by a simple external stand. This horizontal movement brings the grid in close touch with the supported patient preventing the effect of the above-mentioned movements. The base (together with the camera, grid and projector) may be tilted 90 degrees, thus enabling the use of the system for supine or prone lying patients. Initial results of using the above system are presented and discussed in the light of former invasive studies.

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Moiré topography for the study of multiple curves in the spine

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Moiré topography is applied to obtain quantitative information about the multiple curves of the spine. Techniques for measuring the angle of spinal curvature are given. A mathematical formulism is proposed to estimate the degree of correction of spinal deformity.

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The assessment of rib cage deformity in scoliosis

P. H. Dangerfield* and J. S. Denton**
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**Royal Liverpool Children's Hospital
Liverpool, England

A study of the changes in the shape of the rib cage has been undertaken using two relatively inexpensive methods of recording the rib-hump pattern associated with scoliosis. It has been previously reported that the use of the Formulator Body Contour Tracer to calculate the Trunk Asymmetry Score is a good clinical alternative to repeated radiographic methods of recording curvature. We now report on the correlation of this method and the use of the Scoliometer in a study of children with various types of scoliosis. The findings indicate that changes occur in the rib-cage profile which are related both to treatment and the underlying curve pattern. The Scoliometer proves to give valuable clinical results which complement the Trunk Asymmetry Score and serves to demonstrate a previously unrecorded relationship between spinal curve angle and the magnitude of the rib-hump. A study of parents of patients has also been conducted. It has been demonstrated that there is no measurable rib-hump in the parents which suggests in this series that there is no inherited pattern for the rib-hump in scoliosis. The findings for different types of curve pattern indicates that asymmetrical rib growth may play a role in the pathogenesis of idiopathic scoliosis. The use of the Formulator and the Scoliometer are both felt to give simple and easy to use methods of clinically assessing scoliosis.

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Radiographic reconstruction of 3-D human rib cage

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Measurements of rib cage shape in scoliosis would be useful for explaining the overall truncal asymmetry. This paper describes a new photogrammetric principle, based on the "contour radiography" method of Szirtes (1981), applied to reconstruction of rib shapes from stereo radiographs. Based on the assumption that ribs could be approximated as lines, an iterative method for finding corresponding points on these lines for 3-D reconstruction was developed. Rib shape parameters were then derived.

A standard PA x-ray view and a second view with the tube moved up, forming an angle of 20°, was used to make a stereo pair of the rib cage. Eleven arbitrary points were marked on the lines drawn on the middle of each rib image. Cubic splines were then used to approximate the 2-D rib image shape functions. The 3-D error obtained from the Direct Linear Transformation (DLT) reconstruction program (Marzan, 1976) was used for optimising the correspondence between points on rib image line #1 and rib image line #2. Accuracy studies showed maximum error less than 5 mm (S.D.= 0.72 mm).

Rib shape was described by intrinsic parameters (arc length, curvature, enclosed area, end-to-end and side-to-side linear dimensions) and by angulation parameters (frontal and sagittal angulations with respect to the transverse plane). In two rib cages without spinal asymmetry the intrinsic parameters show differences between right and left side less that 5% and the angulation differences were within 5°. In 20 patients with right thoracic adolescent idiopathic scoliosis, the maximum rib asymmetry was detected at the apex of the curve. The general pattern of asymmetry indicated greater arc length, area, curvature and frontal angle on the convex side and lesser end-to-end linear distance and lateral angle on the concave side.

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Rib cage rotation, spinal deformity and surface topography

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It is possible that rotation of the ribs is the 'missing link' explaining in part the relationship between spinal deformity and the back surface. Twenty-two patients with right thoracic adolescent idiopathic scoliosis (Cobb 5° to 56°) were studied. Stereo radiography and rasterphotography were used to record the spine and back surface shape in three dimensions. A new method (described in a companion paper at this meeting) was used to obtain a 3-D line reconstruction of the ribs from the stereo radiographs. Three measures of axial rotation of the trunk were derived: vertebral rotation, back surface rotation and posterior rib rotation, the latter two both measured by a similar double tangent method. For each patient the maximum value of each rotation measurement and the anatomical levels where they occurred were noted.

High correlations between all three rotations were found (r= 0.7 to 0.8). The slope of the regression line indicated that the vertebral rotation and the posterior rib rotation are approximately two times greater than the rotation of the back surface. Consequently, there was roughly a one-to-one relationship between rib rotation and vertebral rotation. On average, the maximum vertebral rotation was at the apex of the curve or within one anatomical level, as expected. Both the rib rotation and the surface rotation were found to be maximal one or two vertebral levels below the curve apex.

Since the rib cage rotation and the vertebral rotation were highly correlated in magnitude and level, it appears that the soft tissue and scapula overlying the ribs might be responsible for the back surface being less rotated.

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Transverse asymmetry measured by ISIS and vertebral rotation

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Vertebral rotation is a significant factor in the assessment of scoliosis and of the cosmetic deformity associated with it. Although various methods for the measurement of vertebral rotation from plane radiographs have been proposed, the results of the different methods are highly variable. These variations are associated with the difficulty in projecting a three-dimensional quantity on to a two-dimensional radiograph.

Transverse asymmetry of back surface shape presented by the ISIS analysis quantifies cosmetic deformity and gives a measurement of the skin surface rotation resulting mainly from vertebral rotation.

This paper reports the examination of 25 patients over a period of 2 years. Vertebral rotation was calculated from x-ray measurements and transverse asymmetry from the ISIS analysis. It is shown that the x-ray measurements were inconsistent, but the ISIS transverse asymmetry provides a more consistent measure of the effects of vertebral rotation and a record of progressive scoliotic change when it occurs.

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Application of AUSCAN system for evaluation of postural changes induced by a brace

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The use of a brace in scoliosis treatment is largely adopted to force modifications of spinal geometry according to the patient's anatomical and physiological characteristics. The long term effects induced by such modifications, involving both spinal curvatures and trunk rotations, are difficult to estimate when the brace is worn the first time but, in general, an improvement of morphological and biomechanical characteristics of the back during postural bracing must occur. Common tools available in clinical practice allow the control of just the back morphology, but disregard objective information about the load supported by the spine. In order to approach quantitatively this problem the AUSCAN system, whose first prototype was presented at the last meeting held in Oxford in 1984, has been used. Seven female patients, aged from 12 to 15 years, have been tested while standing with and without their brace. The resulting postural differences have confirmed the validity of a biomechanical control on the effects induced by bracing, and the usefulness of the data obtained both for treatment planning and for orthesis design.

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Moiré and deformities of the vertebral column

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In Portugal, we began using the moiré technique three years ago to diagnose deformities of the vertebral column (scoliosis, hyperlordosis and kyphosis). We are calling this method "dorsal stereometrics".

With this method, we observed that it was possible to study differences in the height of various segments of the human trunk, its symmetry or asymmetry, and even conduct an anteroposterior study of not only physiological curvatures of the vertebral column (convexities and concavities), but also unilateral differences. In other words, with the moiré technique, we can clearly identify a patient in whom the left or right side of the trunk is more posterior than the other. This is a three-dimensional aspect which neither x-rays nor clinical examinations can reveal.

Thus, stereometrics was introduced in Portugal as a complementary diagnostic technique.

In conducting the metric study, we chose as points of reference a number of surface segments of the human body visible to the naked eye. Other points, such as the C7 spinous process and the posterior sacral foramina, were identified through palpation. This gave us a number of measurements (differences in height, symmetry and depth) which served as the point of departure for the comparative study which is now the focus of our endeavours.

We are currently studying the effects of corrective postural therapy, "shifting", and the insertion of prismatic lenses. The correction is evaluated immediately, and with repeat examinations every three or six months.

We will be presenting comparative spinal stereometric analyses conducted at the beginning, middle and end of the pregnancies of women with pre-existing deformities of the vertebral column. Some achieved a postural correction through remedial gymnastics during their pregnancy, while others did not do this corrective gymnastic. We studied these cases over time, in comparison with one another, and are beginning to obtain results supporting this type of correction.

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Three-dimensional analysis of the effect of brace treatment on idiopathic scoliosis

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The cosmetic effectiveness of brace treatment has not been well evaluated. This study was undertaken to examine the change in back shape with brace by use of moiré analysis. Moiré topograms of one hundred patients with idiopathic scoliosis, taken at the initiation of treatment and at final follow up, were studied together with radiographs taken at the same time. The moiré topograms were analysed for hump height, hump angle, waist line asymmetry index, kyphosis index and lordosis index. Fifty-nine patients were treated with the Milwaukee brace (MB), twenty were treated with the Boston brace (BB), and twenty-one were treated with the Boston-Milwaukee brace (BMB), which was used for a double primary curve scoliosis. The follow up duration was from 2 to 5 + 7 years (mean 3 + 7).

Results:

1. In more than half of the cases of every type of brace, a reduction of hump height of over 5 mm was recognised. The average correction rate of hump angle was 26% in MB patients, 36% in BB patients and 56% in BMB patients (lower curve), which were much higher than the corrections in Cobb angle: 4% in MB patients, 13% in BB patients and 4% in BMB patients.
2. With the reduction of the major hump, appearance of a new hump, or deterioration of a small pre-existing hump, was found at the upper level of the major hump in 22% of the MB patients and 45% of the BB patients. It is thought that this phenomenon should be carefully monitored in brace treatment.
3. The severity of the initial Cobb angle did not correlate with the hump correction results.
4. The hump correction for the group with fully excursed iliac apophysis was not particularly poor. Thus, there seems to be positive indication for brace treatment in this group.
5. In more than 40% of the cases of every type of brace, a reduction of waist line asymmetry index of over 10 mm was recognised. The average correction rate was 33% in MB patients, 17% in BB and 24% in BMB. An over-correction was seen in many cases using BB.
6. There was a tendency for the sagittal contour of the trunk to become flat by wearing BB or BMB, and for lumbar lordosis to slightly increase by wearing BB.

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Measuring changes in posture during pregnancy

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Employing back-view moiré photographs the question of variations in body posture in the course of pregnancy (normal lordosis) is approached. Experimental results are also given.

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A multicentre study by the British Scoliosis Society on back shape in 5350 healthy children

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In 1983, a report of the British Orthopaedic Association and the British Scoliosis Society (BSS) concluded that it should not be national policy, at present, to screen children for scoliosis routinely throughout the United Kingdom (Brit Med J 287, 963, 1983). More data were required. To achieve this aim, the BSS established a "Study Group on Screening and Natural History" in April 1983. It is multidisciplinary and consists of a Chairman, 14 members and 22 advisers, 24 of which are scoliosis surgeons. Six meetings were held between November 1983 and March 1986.

A Multicentre study started in September 1984 in five centres, namely: Colchester, Liverpool, Newcastle upon Tyne, Nottingham and Southampton. The study population involved 5456 children aged 11 – 15 years, 5350 of which were Caucasian to which this report relates.

Each child was examined quantitatively with the Scoliometer in two positions: (1) A standard standing forward bending position (Burwell, James, Johnson, Webb and Wilson, J Bone Joint Surg 65-B, 452, 1983); and (2) A standard sitting forward bending position which involved placing the head between the knees with the spine flexed. Recordings of angle of trunk inclination from the thoracic and lumbar regions were made in each of these two positions (static findings). A derivative was calculated, namely, "standing-minus-sitting ATI" for each of the thoracic and lumbar regions; this figure gives any positional hump change of ATI caused by sitting and forward flexion of the spine (dynamic findings).

In addition to collecting this quantitative ATI data, recordings were made of the following: visual back shape appraisal, the presence or absence of an observed surface lateral spinal curve, decimal ages, sex, ethnic group, stature, menarchial status, handedness and whether or not the child was referred to hospital. After coding, 37 recordings for each child were stored on file for statistical analysis using a computer.

In the children referred to hospital, a further examination, including use of the Scoliometer, was performed. Spinal radiographs were measured for Cobb angle, Perdriolle rotation and sacral tilt.

The findings of this multicentre study relates to:

1. Static ATI findings.
2. Dynamic ATI findings.
3. Hospital referrals.
4. A new screening method.

Particular attention will be given to hump dynamics as revealed in the backs of healthy schoolchildren.

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The international assessment of back shape and analysis using ISIS

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Three centres in the United Kingdom, four in the United States and one in Canada have agreed on a uniform method for the collection of both back shape data, gathered using the commercial ISIS instrument, and conventional clinical information. Data are being returned to the Oxford Orthopaedic Engineering Centre where a statistical analysis is being performed for the period up to December 1987.

The Evaluation is intended, i) to determine the extent to which back shape, as measured and analysed using ISIS, can provide a monitor of the severity and progression of idiopathic scoliosis, with limited resort to radiographs, ii) to identify those features of back topography which are most closely related to the severity of a scoliotic curve, both with respect to skeletal changes and cosmesis, and iii) to investigate the practicality of using ISIS for monitoring scoliosis with and without radiographs.

This paper describes the protocol to which participating centres are adhering and reports the current state of the Evaluation.

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Survey of normal adolescent back shape as measured by ISIS (Integrated Shape Investigation System)

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In the Edinburgh Scoliosis Clinic, ISIS, the newly developed equipment for measuring back topography, has been used routinely since August 1985. In the light of this experience it was felt that data on the normal back was necessary as a reference for comparison, especially with some of the very minimal curves which are sometimes referred.

The results of a survey of the back shape of 100 adolescent subjects as measured by ISIS will be presented.

Other recognised tests have been used in conjunction with the ISIS measurements to help determine and eliminate from the data those subjects who would qualify for referral to a scoliosis clinic.

The remaining data, analysed and compiled into a 'profile of a normal back' as viewed by ISIS, will be presented. It is considered that this pilot study will be of great interest to the growing number of ISIS users worldwide.

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A study of the lateral curves of the spine in teenagers and middleagers with a spinal pantograph

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A non-invasive device, the spinal pantograph, has been used to evaluate variations of the posture during the growth period and in middle age.

At 16 years of age, the kyphosis was 37.4 ± 8.7 degrees and 34.5 ± 7.6 degrees in boys and girls, respectively. Corresponding values for lumbar lordosis was 33.6 ± 8.6 and 36.7 ± 7.6 degrees.

In a sample of 55 year old men and women, the kyphosis was 43 ± 10 degrees and 37 ± 10 degrees, respectively.

A slight increase in kyphosis was seen in both sexes with age. There was no corresponding increase of the lordosis among women. In men the lordosis curve decreased with age.

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School screening: a new pilot study in Vienna

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A pilot study of over 3000 pupils was done using moiré topography for detecting early backshape deformities. The children were divided into two age groups. A team screened the school classes, boys and girls mixed, by first taking a medical examination and using special moiré equipment. The topograms were evaluated by three independent observers. The children in suspect were invited to undergo a clinical examination including a low-dose x-raying. During the work a lot of problems arose, showing the benefits and disadvantages of a future general screening program. The results and conclusions will be presented.

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Kyphosis and lordosis measured by ISIS: an appraisal on a plaster model, healthy subjects and patients with low back pain and scoliosis

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ISIS was evaluated on the plaster model of a patient with idiopathic scoliosis with respect to measured kyphosis and lordosis for reliability in several positions for each of the erect position, "flexion", and rotation. In the erect position, kyphosis and lordosis were measured to an accuracy of ± 1.5 mm (SD). Rotation and "flexion" each altered the mean measurements of kyphosis and lordosis.

In 20 young healthy adults (10 male and 10 female), the reliability of ISIS to measure kyphosis and lordosis was assessed in each of four standard standing positions, namely:

1. Arms abducted 30° from the side.
2. Arms held out in front.
3. Arms folded across the chest.
4. Hands placed on the head.

The findings showed that changes in kyphosis and lordosis each related to position and sex. In position (4), the kyphosis was significantly smaller, and the lordosis larger than in the other three positions with differences in lumbar region related to sex.

In selected subjects with chronic low back pain (10 male and 5 female aged 16–40 years) examined by ISIS in the four standard positions, there was a tendency to be less change in the sagittal curves compared with the normal subject; but this was statistically significant for only the kyphosis in males.

In 14 subjects with idiopathic scoliosis (4 male and 9 female aged 11–26 years), the boys showed no significant alteration in sagittal curves with positional change. The scoliosis girls, like the normal subjects, showed a statistically significant alteration in sagittal curves when the hands were placed on the head.

It is concluded that ISIS measured kyphosis and lordosis reliably. Moreover, it reveals changes in sagittal curves brought about by altering the position of the subject which has clinical relevance.

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Back shape and scoliosis: a comparison of measurement techniques

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The exact role of back surface measurement methods in the management of scoliosis is not yet well defined. In order to study the relationships of back surface shape to the spine shape, four different measures (two radiographic and two topographic) were compared in 106 patients with adolescent idiopathic scoliosis. These patients were examined radiographically with stereo paired x-rays, and topographically using moiré topography and rasterstereography. There were 155 curves in this patient population with an average Cobb angle measured radiographically of 21 degrees. Comparison measurements were made between lateral deviation of the vertebral centers as projected on PA x-ray, pedicle rotation measured from the stereo paired x-rays, back surface axial rotation of a double tangent (DTAN) measured from the rasterstereograph and angulation to the horisontal of fringes of equal order as measured by moiré topography (MOWMO). Measured values for each technique were plotted against each vertebral level and portrayed graphically. Angular measurements of end points of curves in these graphs gave values in a manner similar to the Cobb angle measures usually obtained using x-rays alone.

Four categories of agreement were found between the four separate measures. Group 1 comprised 71 patients in which there was complete agreement on the presence, level and side of the curves. Group II comprised six patients in which the x-ray findings and moiré findings agreed but not the DTAN measurement. Group III comprised four patients in which the MOWMO disagreed. Group IV comprised twenty-three patients in which neither DTAN nor MOWMO agreed with the x-ray. This group included ten patients who had non-standard rotation radiographically in single curves. Using both the DTAN and MOWMO topography measurements, correct curve location with respect to side and region was identified in 130 (86.4%) of the 155 curves. DTAN alone was correct in topographic, and radiographic measurements of the curve magnitude were between 0.7 and 0.8. It appears that back surface shape can be accurately measured by more than one topographic means with excellent correspondence (83%) between these measures. The ability of back surface shape to identify the site of a true structural scoliosis is extremely high.

Comparison of determination parameters of spinal deformity by using optrimetric, ultrasound and x-ray methods

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In the last years we have gained experience with two methods for determination of surface topography:

1. With the optrimetric method we obtain a three-dimensional surface by registration of distortion of parallel lines projected on a human back.
2. Secondly, with ultrasound emitters, which are attached to predetermined points of the bony structure of the shoulder and the pelvis. A mobile ultrasound emitter is moved down the spinal processes. By measuring the time elapsing between emission and reception of the ultrasonic signals, the exact position in space of these points are determined.

Investigations of spinal deformities performed over several years have demonstrated that it is necessary to maintain distinct posture parameters. To obtain an optimum of reproducibility and comparability, always the same points have to be measured. In this way the posture in space of the body can be determined in a more exact way than is usually possible with x-rays. Only an exact assessment of the change of body posture in space will allow an exact diagnosis of an ongoing pathological process in the spine.

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A comparison between ISIS and the moiré method in the assessment of scoliosis

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Thirty patients with scoliosis have been examined with ISIS, moiré topography and x-ray pictures, and the results have been compared. The correlation coefficient between the Lateral Asymmetry Index of the ISIS method and the Cobb angle was 0.6 if all cases were included. It rose to 0.76 if the congenital cases (two patients) and the operated cases (four patients) were excluded.

The moiré method showed a lesser degree of correlation to the Cobb angle. The correlation between various parameters in the ISIS scans and the moiré pictures varied, the correlation was highest between the thoracal kyphosis (r=0.85) and parameters associated with the rotation of the trunk below the shoulders (r=0.75). These parameters were also compared with the rotation of the apex vertebrae in the x-ray pictures. The results are discussed.

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Comparative study between the ISIS, moiré topography and the Sangamo Transformer in the detection of scoliosis

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A plaster model of a scoliotic patient is measured using the Sangamo Transformer, moiré topography and the ISIS system. The reproducibility of all measurements is determined for the three different systems and the results are compared.

The ISIS measurements are analysed by means of the latest software edition of Oxford Metrics. Finally, the reproducibility of the ISIS system is verified on the normal back of a live subject and on those with different scoliotic curvatures.

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ISIS and the Scoliometer: hump dynamics in patients with idiopathic scoliosis

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This paper reports the hump changes in scoliotic patients moving from a standard standing erect position to a standard sitting forward bending position and involving spinal flexion.

Thirteen patients aged 9–29 years with idiopathic scoliosis attending the scoliosis clinic were measured in considerable detail. All had adolescent scoliosis except one, who had juvenile idiopathic scoliosis (males 2, females 11).

Using ISIS, the back of each patient was scanned four times in a standard standing erect position, with the subject moving around the room between each scan. Then the back was marked into 10 equal divisions, or levels, to correspond closely with each level created by ISIS. In a standard sitting forward bending position, the Scoliometer readings were obtained successively by one observer as a set at each of the 10 levels. Four sets of such readings were obtained with the patient moving around the room between each set of readings. In analysing changes of angle of trunk inclination caused by altered sagittal plane position of the patient, the mean maximal ATI was calculated separately for each of the thoracic and lumbar levels in the two positions.

On anteroposterior spinal radiographs obtained in the standing erect position, the following were measured: the Cobb angles of the major and the minor spinal curves; and the degree of axial vertebral rotation of the apical vertebra in each of these curves using two methods (for spinous process rotation, Bunnell's template and for pedicular rotation, Perdriolle's torsiometre).

In the thoracic and lumbar regions there were significant differences between the mean maximal ATI's recorded by ISIS in the standard erect position and by the Scoliometer in the standard sitting position ($p < 0.001$, analysis of variance). In the thoracic region, this was due mainly to reduced mean maximal ATI readings in the sitting forward bending position. In the lumbar region, the positional change in mean maximal ATI (change in hump rotation or more briefly "hump rotation") was related to the type and side of mainly spinal curves.

In the thoracic region, there was no correlation between the positional change in mean maximal ATI and (a) each of spinous process rotation and pedicular rotation and (b) Cobb angle. In the lumbar region, there was a statistically significant correlation between the positional change in mean maximal ATI (hump rotation) and each of spinous process rotation and pedicular rotation ($r = 0.74$, $0.001 < p < 0.01$ and $r = 0.79$, $0.001 < p < 0.01$, respectively) but not with Cobb angle ($r = 0.35$).

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A comparative study of sagittal spinal thorac-lumbar curves using flexible rule and moiré contourgraphy

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A method of deriving sagittal spinal thoraco-lumbar curves using the moiré contourgraph has been described. The data was tested to assess the need for an error correction procedure in the methodology. It has been shown that it is important to use the actual individual fringe interval, and an individual calculated scale factor for each moiré fringe level. A comparative study of 30 flexible rule curves and 30 moiré-derived curves has been carried out. Mathematical models were fitted to the data by the use of cubic spline regression analysis and the curves for the flexible rule and the moiré models were compared using Student's *t* test. Normality was tested by converting the data to factor scores.

The results have shown that there is no significant difference between the two methods for deriving sagittal spinal curves, and that the curves used in the study fell within the normal range. Neither these results, nor the shape of the curves were influenced by the age, weight or height of the subjects used in the study.

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The analysis of human back shape asymmetries by computer algorithms

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In the literature there exist many proposals for describing a human trunk, if the geometry of the body is fed to a computer by some image processing device. We compared the CMCT, or double tangent curve, with the rotation and asymmetry factor according to Hefti. Applying a mathematical convolution operation, we calculated, in addition, a shift factor of the trunk's lateral deviation by a computer algorithm needing no operator's interaction. The resulting parameters describing the back's asymmetry were tested against the clinical findings of a group of scoliosis patients.

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Shape analysis of the human back: automatic localization of anatomical landmarks and assessment of lateral asymmetry

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The localization of anatomical landmarks on the back surface is of considerable interest in establishing quantitative correlations between back shape and the underlying skeletal structures. Certain landmarks may be utilized to define a body-fixed reference coordinate system which, in turn, enables an objective and quantitative description of lateral asymmetry and other deviations such as pelvis tilt.

The present paper describes a method for an automatic detection of the vertebra prominens, the dimples of the posterior superior iliac spines (PSIS), and of the sacrum point which is located at the beginning of the rima ani. The procedure is based on surface curvature analysis, since these landmarks are all characterized by a peculiar pattern of surface curvature.

In a first step, a "symmetry line" is constructed which divides the back surface into a left and a right portion, with minimum lateral asymmetry at each level. The symmetry line is approximately located in the medial sagittal plane, showing a lateral deviation in the case of scoliosis. It is expected that the lateral deviation is quantitatively correlated with spinal curvature and vertebral rotation. Some examples of a qualitative correlation are demonstrated.

The landmarks of the vertebra prominens and the sacrum point are expected to lie on the symmetry line. In more than 95% of the patients, they are easily localized by searching along the symmetry line for points showing a characteristic curvature pattern. Once these basic landmarks are detected, the dimples of the PSIS are easily localized to the left and to the right of the symmetry line at a certain fraction of the C7–sacrum distance.

The construction of the symmetry line and the detection of the landmarks are described in detail. Some examples are presented, and the utilization of the data for objective assessment of back shape deformity is discussed.

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Shape analysis of the back surface: measurement of the lateral tilting of the pelvis from posterior superior iliac spines

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In shape analysis of the back surface, the dimples of the posterior superior iliac spines are used as anatomical landmarks of outstanding importance. Together with the vertebra prominens landmark, they allow the establishment of a body-fixed coordinate system. From the direction of the interconnecting line of the dimples, the tilting angle of the pelvis is determined. However, for these applications, the localisation of the dimples must be known very exactly. It is the aim of this study to give some data on the reliability with which the landmarks are localised in rasterstereographs. In addition, the relation between the tilting angle of the pelvis and the dimples is examined.

In several patients, artificial leg length discrepancies between 0.5 cm and 3.0 cm were introduced in steps of 0.5 cm by underlying boards either under the left or under the right leg. From the height of the boards and the radiological distance of the hip joints, the expected tilting angle of the pelvis can be calculated. In each position a rasterstereograph was taken and automatically evaluated. By curvature analysis of the back surface, the dimples were localized and their tilting angle was determined.

It was found that there is a very good correlation between the artificial leg length discrepancy and the tilting of the dimples ($r = 0.95$). The scatter of the angles is about 1.0°. However, in several patients the tilting of the dimples differs by a factor from the expected tilting of the pelvis. Possible reasons for this discrepancy will be discussed.

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Variability due to subject positioning

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The variability of three methods of patient positioning procedures were determined. Repeated moiré topographs were taken of three normal subjects in each position. The positions tested were:

1. unobstructed free standing (Armstrong);
2. inclined positioning to ten degrees (Ohtsuka);
3. seated forward bending positioning (Harada).

Subsequently, one scoliotic patient was repeatedly positioned in each of the positions.

Results indicated that the variability between trials and between methods of positioning normal subjects for four out of five measurements examined was insignificant. However, the lateral deviation measure was significantly different between trials ($p < 0.05$), and between methods ($p < 0.05$).

The variability for repositioning a scoliotic patient in the same positions was significant for three out of five measurements. The difference between methods was significant for the measures, including rib hump height ($p < 0.001$), and the rib hump index ($p < 0.001$). The differences between trials were significant for rib hump height ($p < 0.001$), and rib hump index ($p < 0.05$).

The differences between normals and the scoliotic subject studied raises questions regarding the reason for the differences found. We recommend that a study of the variability due to subject positioning be conducted with scoliotic patients.

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Foot shape representation for a CAD application

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Development of computer aided design for custom orthopaedic footwear has prompted this work into foot shape representation. Working from a model of the surface topography of the foot, the shape will be adjusted to form a shoe last or mould for a custom shoe insert. The immediate problem is to develop a surface model which can be matched to the real shape of the foot, and which can easily be adjusted during the CAD process. The method of B-splines defined by a control polygon has proved to be a powerful tool for surface adjustment. An iterative method is presented by which pointwise data can be fitted with such a B-spline curved surface. The form of the data point set needed for input is topologically a rectilinear grid, allowing a range of shape sensing techniques to be used. The fit of the curves is shown to be adequate for good representation of the foot. The local, variation diminishing properties are suitable for this CAD application, and the representation is efficient in data storage.

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Analytic assessment of back symmetry and its reliability in a clinical setting

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The Bioengineering Division of this Hospital, in conjunction with the Scoliosis Clinic that services the State of Western Australia, has been investigating moiré topography techniques in the measurement of spinal deformity. This work has been funded for 3 years by the Telethon Research Foundation.

The emphasis in the research is not on the development of the technology with which to produce the topograph, but is on the efficacy of the technique as a clinical tool and, in particular, to judge that efficacy against the traditional methods.

Moiré topography, an optical method through which one can develop contours and sections describing back shape, is being used in a number of centres around the world to assess scoliosis. Analysis varies from the qualitative assessment of the topograph through to mathematical description of asymmetrical changes in back shape. The method is used to qualify clinical observations of asymmetrical changes to the trunk in forward bending and from the use of P-A radiography. The problem as seen by the research team is that the changes occurring to the back with scoliosis is a second (or third) product of the primary pathology. Lateral collapse of the spine causes (or occurs with) vertebral rotation which, in turn, causes the trunk deformity. The overlay of soft tissue, scapular structures, etc. on the deformed spine gives rise to the deformity observed by the method. Under investigation are the factors affecting asymmetry, the reliability of measurement in a climate of changing posture and variations in body positioning between measurements, and the development of a reliable index of asymmetrical change. If moiré topography is to become a recognised primary diagnostic and measurement tool, it must be able to discern, sensitively and accurately, changes in lateral curvature of between 5–10 degrees. Importantly, the clinical community must have the confidence to act upon the results, an action which may result in extensive spinal surgery in cases of progressive pathology unsuited to conservative treatment, e.g. by bracing.

The mathematical processes of data correction and the generation of parameters describing back symmetry will be presented. The results of a patient positioning study using combinations of feet, hip and shoulder constraints will be reviewed. In order to assess the ability of the technique to identify change, serial sudies were performed on data collected from the Scoliosis Clinic over the last 6 years. The results of these studies will also be presented.

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Dynamic moiré topography for the assessment of spinal deformity

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Back pain and nerve root symptoms can be caused by postural imbalance of the spinal column. Moiré fringe patterns are a useful adjunct in the evaluation of patients with conditions either caused by or causing body asymmetry. Prior to their development, clinical assessment relied upon the simple use of tape measures or clinical photographs; however, errors are easily made if the patient is measured in an incorrect posture. Static moiré fringe photographs offer little advance in this respect. Fringe patterns can be produced either by a grating or by photographic projection. We report on our three years experience using the grating method. The fringe patterns can be viewed immediately during the assessment of patients thereby facilitating the evalution of the effects of changing the patient's posture.

A dynamic record of the complete assessment is kept using standard video equipment so that further analysis is always possible. A video image frame store (Image 3 Frame Store plus BBC Computer) is connected to the system so that two images can be accurately superimposed and compared. These can be either before and after a postural correction such as a heel raise, or used to assess postural changes between visits to the clinic.

At present, a clinical trial to validate the use of this technique to assess leg length discrepancies is nearing completion. In this trial patients presenting with back pain and/or sciatica accompanied by leg length inequality are assessed both by moiré topography and by standing pelvic x-ray. Correction is then prescribed, randomly based on one or the other method, and the patients reviewed after intervals of two and six months. Initial results suggest comparable levels of symptomatic improvement for each method. Formal statistical analysis is planned for when 50 patients have completed their follow-up periods and will be presented at this meeting.

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Real time analysis of moiré pictures in the scoliosis clinic

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One of the problems in the application of moiré topography to the scoliosis clinic is the time lag between the measurement and the analysis. A polaroid picture is too small to analyse accurately. We developed a real time analysis system for moiré pictures in the scoliosis clinic using a still video camera and a micro computer system.

The moiré picture of a scoliosis patient is taken and displayed on a TV moitor screen by a still video camera and a floppy disk player.

The picture is analysed and the hump index and the waist line asymmetry index are calculated by the micro computer system. Three hump indices are calculated by dividing the difference of the height of the hump by the trunk width at three levels: thoracic, thoracolumbar, and lumbar. The total sum of the three indices is shown as the hump sum. The whole procedure is done in five minutes.

With this system it is possible to minimize the radiation exposure in the scoliosis clinic if the change of the hump sum corresponds to the change of the Cobb angle.

Since October 1980, we have taken moiré photos routinely in our scoliosis clinic. The details of the system and the preliminary results of the analysis of the hump sum will be shown.

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Moiré topogram production and analysis at NRC: a status report

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The Photogrammetric Research Section at the National Research Council of Canada has been investigating moiré topography for over 10 years. Most of this effort has been inspired by a particular application, namely, the determination of the surface topography of the human back for the detection and diagnosis of spinal deformity. This paper reports upon the status of the developments in this field at NRC.

Some of the design aspects of the NRC shadow-type moiré instruments will be described, with emphasis upon recent refinements in a continuing effort to improve the quality of the moiré topogram. A new lamp housing that reduces stray light, a periscope that reflexes annotation into the topogram, and a motorised (instead of falling) screen translator have been investigated.

The NRC Standard Object for Moiré Topographs was described at the Münster meeting. Since then, a suitable shipping case has been fabricated, and the test object has been loaned to various institutes for the photogrammetric evaluation of moiré and other shape measuring techniques.

Special hardware for electronic imaging, processing and storage of moiré topograms for scoliosis screening has been developed at NRC, and while only reviewed here, it will be reported in detail in a companion paper at this meeting. At the software level, advances in automated analysis to ordinary topograms have also been realised. In particular was the resolution of the *hill-and-valley* dilemma using a shading analysis technique first proposed at the Oxford meeting. Termed "photometric ordering", the details of this new method will be described in a third paper at this meeting.

Moiré topography is only one of several surface measuring techniques that uses *structured light* to encode the 3-D nature of a surface in a single 2-D record. Rasterstereography constitutes another class well represented at these meetings, either based upon projecting whole grids, or arrays of dots or lines, or else based upon scanning discrete raster lines, as in the ISIS system. Some of the attributes and limitations of these structured light technologies will be compared in terms of suitability for various applications.

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Photometric ordering of ordinary moiré fringes

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A commonly cited problem with moiré topogram analysis is the *hill-or-valley* dilemma. It stems from the task of ordering the surface contours represented by the moiré fringes, according to their relative altitude above the reference plane. The fringes of an ordinary moiré topogram are: 1) fixed in the image (*fixed encoding*) and 2) sinusoidally symmetric in the direction of the surface gradient (*grade symmetric*). So in the absence of additional information, there is an ambiguity as to whether a contour lies above or below the neighbouring contour. *A priori* knowledge of the nature of the surface usually will provide sufficient guidance to resolve any ambiguity, but this knowledge is difficult to incorporate into an automated system, even for a limited class of simple objects (e.g. the human back).

For applications involving arbitrary shapes, one may depart from the constraints of ordinary moiré by encoding additional information into the topogram. Fixed-encoding methods have succeeded either by using intensity modulation via asymmetric gratings and moiré/raster combinations, or by employing spectral modulation achieved either through asymmetric colour gratings or by double exposure, 2-colour shift encoding. On the other hand, grade-symmetric moiré topograms have been automatically analyzed by scanning methods using phase-lock techniques with dynamic fringe patterns to resolve the surface gradient sign.

In this paper, it is shown that there is sufficient information already in the ordinary moiré topogram to resolve the *hill-or-valley* dilemma. That information lies in the *shading*, or local surface reflectance, a measure that is functionally dependent upon the orientation of the surface with respect to the light source and the observer. In most cases the ambiguous choice between *up* or *down* leads to such disparate surface orientations, that the measured reflectance arbitrates with strong confidence. The global connectivity of the fringes allows remote decisions regarding a fringe pair to span regions where the local certainty is too weak.

Some of the theoretical and practical constraints of this "shape-from-shading" method are discussed, and an algorithm for automated fringe ordering is described. Two software programs embodying this technique will be presented, and examples of analysed topograms of test objects and of human backs will be included.

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Electronic imaging, processing and storage applied to scoliosis screening

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Mass screening programs to detect scoliosis using moiré equipment may be facilitated by employing the digital image. A prototype digital electronic image aquisition, processing and storage system for this purpose is described, with some preliminary laboratory results. Its function is to electronically capture moiré topogram images of the backs of subjects in a standardised alignment relative to the screening apparatus, to archive the annotated digital images on a computer compatable medium and to flag which subjects are near normal. The system has the potential advantages of stability, ease of field operation, robustness, moderate cost, image processing features and computer compatability.

Image capture is via a CCD video camera, digitizer and frame grab digital video memory. Real-time custom image processing hardware performs image enhancement and symmetry correlation analysis. The image can be previewed on a display then recorded on a digital disc, after which it can be viewed at once. The ruggedized storage unit can accept up to 40 moiré topogram digital images per removable cartridge, thereby providing essentially unlimited field archiving of moiré topograms in digital form.

This development constitutes one of three components at NRC to effect an ongoing program of screening Canada's school population for scoliosis. The shadow moiré instrument is already a mature component; and the critical and difficult one of automating topogram analysis is meeting with success, as reported separately by colleagues at this meeting. Whether this analysis system can be supported by digital images of standard TV resolution remains an issue to be explored, as does its performance in field trials.

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Moiré contourgraphy on a microcomputer-based image processing system for the detection of scoliosis

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A microcomputer-based (IBM-PC/AT) image processing system is being developed for the analysis of moiré contourgrams digitised from the video output of a commercial moiré camera (Fujinon FM40).

The system will have facilities for image preparation (digitisation, pre-processing and storage), image processing (fringe detection, fringe ordering), feature extraction (digital profile analysis, hump angle, lateral deviation, deviation of fringe interval), classification (statistical and discriminant analysis), and database management (record management, database query and report generator).

Fringe detection is based on a tracking algorithm that uses a cost minimisation technique. Several heuristic rules are selected to aid in the tracking.

The system will be used in the routine screening of school children in Singapore for the detection of scoliosis and should improve the accuracy of diagnosis and the efficiency of the screening procedure. In addition, the database management facilities provide a means for clinical researchers to extract relevant and timely information from the large database of moiré contourgrams that will be built up.

Experience and problems arising from the development and testing of the system will be highlighted.

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Computer-assisted dot array analysis in surface topography: perspectives for clinical screenings in scoliosis

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The projection of patterns of either stripes or grids, or the generation of a moiré topogram, are suitable tools for a clinical evaluation of back surface configuration and symmetry. The clinician can examine either the actual projection on the patient, or a photograph of the projection. Implementation of this kind of acquisition on computerized equipment, to obtain half-automated or a totally automated system of analysis, has been studied by several authors.

When a dot array is used instead of the previously mentioned systems, the picture obtained is not very easy to evaluate directly, but the dot array system gives the advantage that it is easier to develop a computer-based system that starts from this picture. The system would be able to handle the data from tv-cameras or films without any operator interaction, and could process them in order to outline surface features of possible clinical interest.

We are studying the development of a system that projects a dot array on the patient's back. The optical system and the dot array are specially designed to make an acceptable correction to the optical defects, and to maximize the amount of data obtainable by a single picture.

A procedure of recognition of the dot array from the image input into the computer is used. Subsequently, the position of the dots in the three-dimensional space is calculated. On this base, a model of the patient back surface topography is then generated.

Since the basic data (the dots' coordinates) are already extracted, it is possible to further process them with special routines that satisfy the clinician's needs. For example, one can implement an automated determination of parameters of clinical interest, or one can generate colour-coded images that provide an easier interpretation of the pictorial data.

The amount of data stored for each patient is quite small; it is related to the dot density and to the options used (e.g. the storage of coded images). This seems to be of great value in the perspective of large clinical sceenings, as in the case of mass screening of school children.

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AUSCAN system: technological features of the new 3-D version

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Following the previous presentation of the AUSCAN system at the symposium held in Oxford, the main features of the new 3-D version will be illustrated. This version is not just an up-dating of the first prototype, but is the final result emerging from the experience of many experimental tests on patients and normals, from technological improvements, and from clinical suggestions. First, the time taken by the whole test has been reduced by using four TV cameras concurrently, and by multiplexing the signals feeding the image processor. Furthermore, the spatial resolution has been improved to 1/2500 of the TV camera field of view, thus obtaining an accuracy of about 0.8 mm. This result has been made possible by computing the centroid of values of the over-threshold pixels associated with each marker. Finally, a true 3-D measurement procedure for determining marker coordinates has been developed, by combining the information provided by selected pairs of TV cameras. Space resection has been solved by applying an iterative least-square method to linearise the collinearity equations, thus computing concurrently, starting from a set of control points, the nine optical and geometrical camera parameters to be used in space intersection. The latter has been performed by transforming the coordinates of the single marker into object space coordinates for each TV camera, and by calculating the 3-D point coordinates by a least square triangulation performed on the two cameras. System performances, tested by a suitable control object, will be presented and discussed.

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Automatic 3-D measurement by the projection of a grating pattern

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A grating pattern projected onto a specimen shows deformation in accordance with the surface profile. The deformed grating pattern is captured by a TV camera and analysed by computer to give 3-D data and a wireframe model. The automatic system is applied to scoliosis detection and industrial measurements.

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